Fetal arrhythmias as detected by magnetocardiography

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1 Introduction

As routine use of the fetal electrocardiogram (FECG) is difficult, clinical evaluation of fetal arrhythmias is generally performed with M-mode Doppler echocardiography. Assessment of rhythm disturbances is done on the basis of contractile and flow behavior but the method has its limitations. These include the dependency on the investigator's experience as well as restrictions as a result of fetal movement and position [1]. Also, as analysis of the signal morphology is not possible, a differentiated diagnosis of an arrhythmic event may be difficult.

Fetal magnetocardiography offers an alternative as it permits the examination of the fetal cardiac conducting system on the basis of the electrophysiological signal. Fetal arrhythmic behavior has been reported in a number of studies and has demonstrated that magnetocardiography represents a simple non-invasive method in the detection of fetal arrhythmias [2-7]. The work presented here demonstrates the ability of fetal magnetocardiography to record and identify a wide variety of prenatal cardiac conduction disturbances.

2 Methods

We examined 101 pregnant women between the 13th and 42nd week of gestation, of whom 46 were healthy, normal pregnancies. 18 had been referred because of suspected fetal arrhythmia and a further 37 for other reasons (twin pregnancy, growth retardation, pre-eclampsia, previous HELLP syndrome, methadone use).

Using either a 37 channel Krenikon (Siemens, Erlangen) or a 67 channel Magnes 1300C (BTi, San Diego) biomagnetometer, 298 fetal magnetocardiograms (FMCG) were recorded. Data was collected for at least 5 minutes at a sampling rate of 1 kHz and with a bandpass 1-200 Hz. 279 traces (94%) demonstrated sufficient fetal signal strength to permit evaluation, whereby unsuccessful recording occurred only prior to the 20th week. In each recording, the maternal artifact was identified and digitally subtracted using a maternal PQRST template (Fig. 1), after which only a few channels contained a minimal residue of the mother's signal. Subsequently, all fetal complexes were identified either by using appropriate templates or manual marking and the recording was examined for arrhythmic events.

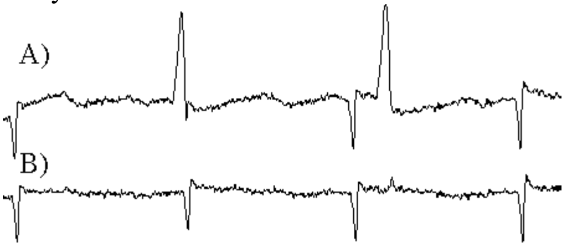

Fig 1: *FMCG in the 29th week of gestation: A) before digital subtraction of the maternal artifact, B) after subtraction.*

3 Results

In 22% of all recordings, short bradycardic episodes (<10 sec) were found, consisting of a sudden substantial RR interval lengthening to at least 150% and as much as 300% of the previous RR interval. The subsequent RR intervals showed a gradual shortening within the next 10-25 beats until the basal heart rate was again reached (Fig. 2).

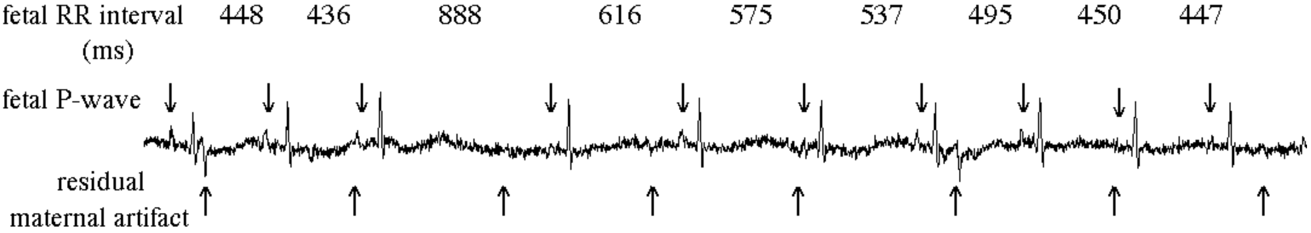

Figure 2: *Example of a short episode of fetal bradycardia in the 31st week of gestation characterized by a sharp decrease in heart rate and a gradual return to basal heart rate (here 140 bpm).*

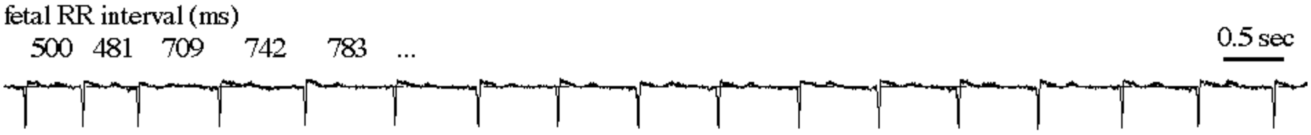

Figure 3: *Episode of fetal bradycardia in the 38th week of gestation demonstrating a drop of heart rate below 100 bpm for more than 10 sec.*

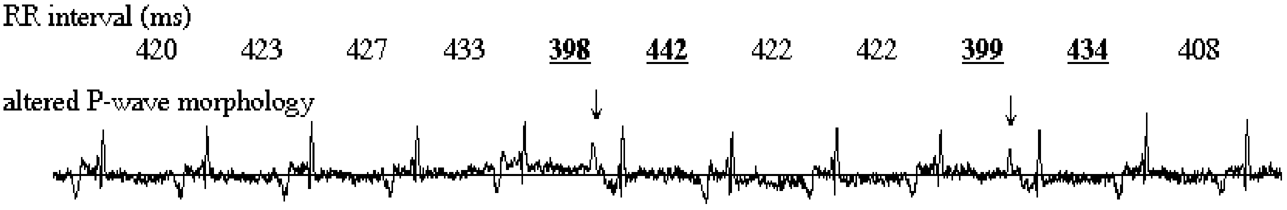

Figure 4: *Supraventricular extrasystolic beats with altered P wave morphology (↓) in a fetus in the 36th week of gestation.*

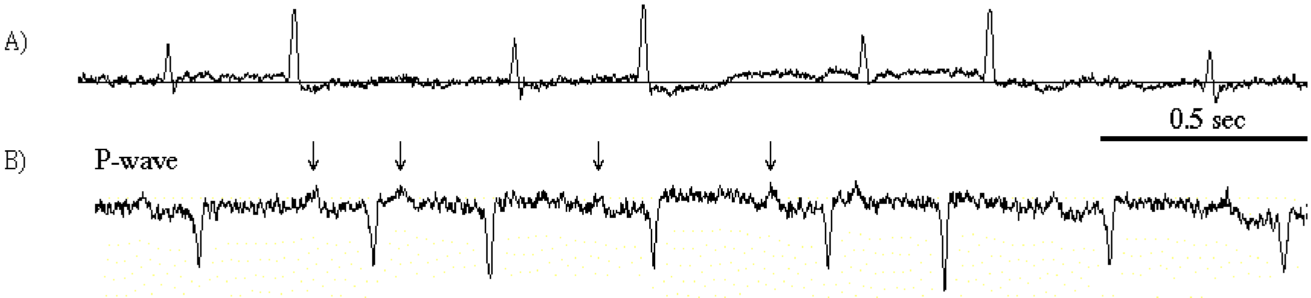

Figure 5: *A) Bigeminy in a fetus in the 34th week of gestation, B) trigeminy in a fetus in the 31st week of gestation; note the P waves (↓) indicating an atrio-ventricular delay in the extrasystolic beat.*

In recordings in which the P wave could be identified (as in Fig. 2), the PP interval also increased, indicating that this phenomena may be associated with sino-atrial block (see also Fig. 6). These episodes were observed more often in mid-pregnancy and were not associated with any pathological condition. As such they should be distinguished from clinically relevant bradycardia, defined as a heart rate < 100 bpm for > 10 sec (example in Fig. 3).

In 15 cases we found isolated extrasystoles, both of ventricular and supraventricular origin, which were of no clinical significance. Figure 4 shows one such case, in which a change in morphology of the P wave prior to the premature complex was apparent, demonstrating the potential of FMCG in morphological rhythm analysis.

In 14 recordings multiple arrhythmias demonstrating a variety of excitation and conduction disturbances were observed. These included ventricular and supraventricular ectopic beats, bigeminy and trigeminy, sino-atrial block and atrio-ventricular conduction disturbances. Furthermore we also documented cases with tachycardia.

Figure 5 shows examples of bigeminy and trigeminy. The former occurred in a case of a fetus with complex arrhythmias in the 34th week of gestation. The latter, in the 31st week, demonstrates multiple supraventricular extrasystoles, including recurring atrio-ventricular delay, which revealed persistent trigeminy. In both cases there was no evidence of arrhythmia in the postnatal period.

Figure 6 is taken from another segment of the trace of the fetus with complex arrhythmias in Fig. 5A. Here there were repeated RR intervals with a period doubling. As signal quality did not permit the unambiguous identification of the P wave, these beats were averaged. The fact that, in the averaged signal, a P wave appeared only prior to the QRS complexes indicates that the conduction disturbance can be classified as a second degree sino-atrial block.

Figure 7 is another example of conduction block (42nd week of gestation). Beside a supraventricular extrasystolic beat followed by a compensatory pause, the trace shows a premature sino-atrial depolarization without subsequent ventricular depolarization. This may be due to a refractory AV node i.e. an atrio-ventricular block. After the child was born,

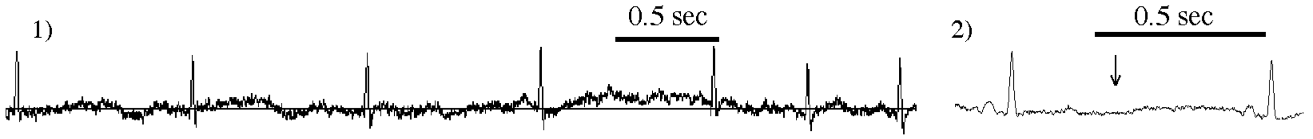

Figure 6: *Fetus in the 34th week: 1) several consecutive beats with period doubling, 2) signal average of these beats, the lack of the P wave (↓) indicating a second degree sino-atrial block.*

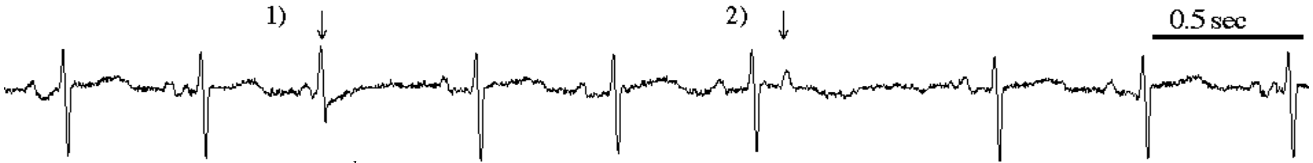

Figure 7: *1) Fetus in the 42nd week: supraventricular extrasystole followed by 2) a premature atrial contraction with atrio-ventricular block.*

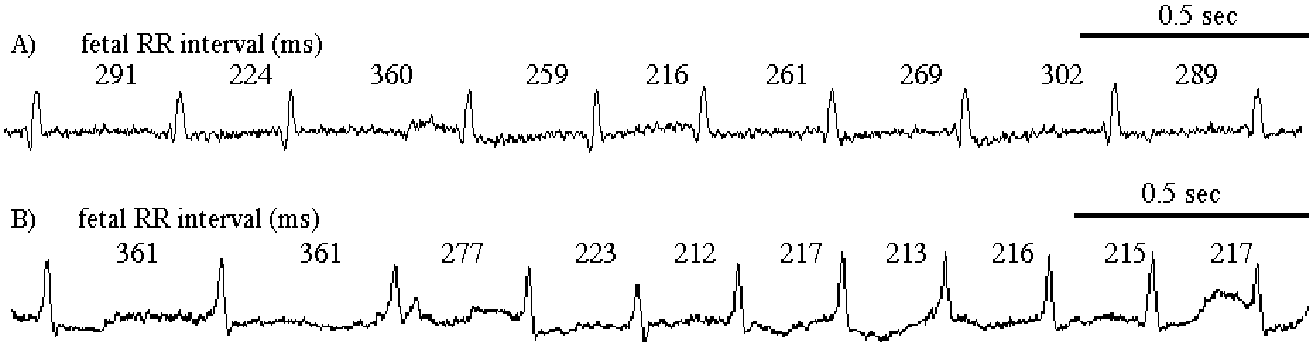

Figure 8: *A) Short tachycardic run in a fetus in the 28th week with absolute arrhythmia, B) Begin of a 10 sec episode of tachycardia (HR ~ 270bpm) in 37th week.*

atrial septal defect with a right-left shunt was diagnosed with a moderate volume overload of the right ventricle. Arrhythmia was not observed in the following half year.

Figure 8 displays two examples of fetal tachycardia. The first is a short tachycardic run in a fetus in the 28th week with absolute arrhythmia. The second shows the begin of a 10 sec episode at a heart rate of 270 bpm in the 37th week. Digital post-processing of the QRS signals revealed a P wave embedded in the QRS complex of the tachycardic beats, suggesting a possible AV node reentry tachycardia or atrial tachycardia with a long PR interval. The mother was put on digitalis therapy and further tachycardia was not observed in a control FMCG. After birth, atrial tachycardia with 4:3 conduction was diagnosed but there was no evidence of an accessory pathway. The new-born was treated with digitalis until the age of one year when no further episodes of atrial tachycardia were observed.

4 Discussion

With respect to the examination of the fetal cardiac electrophysiological signal, magnetocardiography fills the gap left by the difficulties involved in recording the fetal ECG. FMCG can be reliably registered from the 20th week of gestation onward. Signal quality is often sufficient in order to enable identification of not only ventricular but also atrial depolarization. Digital signal processing techniques will aid in the identification and interpretation of relevant signal morphology. These assets will enable differentiated inferences about the origins of the arrhythmic behavior.

In a considerable portion of recordings of normal healthy fetuses we found abrupt shifts to low momentary heart rate which immediately drifted back to the basal heart rate. In cases where a P wave could be reliably identified, there was no evidence of atrial depolarization between the QRS complexes of the long beats, suggesting that the phenomena is due to sino-atrial block or perhaps sinus pause. The reduced frequency of occurrence of this phenomenon with gestational age, coupled with the concurrent increase in heart rate variability as pregnancy progresses [8], may indicate that this reduction reflects the maturation of the autonomic nervous system. It may thus be associated with changes in sympathovagal balance resulting from the overriding of the influence of sympathetic tone by the increase in parasympathetic activity in the course of pregnancy [9].

A number of other conduction disturbances have been described here, some of which were clinically relevant. Apart from these examples, there have also been reports on prenatal atrial flutter and torsade de pointes [2], bundle branch block [2,5,6], congenital complete heart block [4], junctional rhythm [3], WPW-syndrome [6] and long QT syndrome [7]. This variety of fetal conduction disturbances published to date confirms the potential of fetal magnetocardiography. It may be applied in assessing cases with suspected or unclear arrhythmia as well as in the classification of more complex conduction abnormalities. It will thus be useful in the identification of clinically relevant arrhythmia and aid in decisions concerning treatment.

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